

PENGUINS IN CP VIOLATING B DECAYS ¹

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ABSTRACT

The role of penguin amplitudes in CP violating B decays is reviewed, emphasizing recent progress in the analysis of electroweak penguin contributions. It is shown how these terms are included in a model-independent manner when measuring the weak phase α in $B \rightarrow \pi\pi$ using isospin symmetry, and when determining the phase γ from $B \rightarrow K\pi$ applying flavor SU(3). Uncertainties due to rescattering effects in $B \rightarrow K\pi$ are discussed.

¹Invited talk presented at the 17th International Workshop on Weak Interactions and Neutrinos, Cape Town, South Africa, January 24–30 1999

1 Introduction

The long awaited recent report [1] on a clear observation of direct CP violation in $K \rightarrow \pi\pi$ decays, $\text{Re}(\epsilon'/\epsilon) = (28.0 \pm 3.0 \pm 2.6 \pm 1.0) \times 10^{-4}$, is the first evidence for the important role played by penguin amplitudes in the phenomena of CP violation [2]. B decays are expected to provide a variety of CP asymmetry measurements, as well as measurements of certain combinations of rates, some of which carry the promise of determining the angles of the unitarity triangle [3], α, β and γ . This can test the commonly accepted hypothesis that CP violation arises solely from phases in the Cabibbo-Kobayashi-Maskawa matrix [4]. Let us review [5] a few of the ideas involved in this study, paying particular attention to the role of penguin amplitudes.

- β : In the experimentally feasible [6] and theoretically pure example of $B^0(t) \rightarrow J/\psi K_S$ the decay amplitude is real to a very high precision. Theoretically [7], the time-dependent mixing-induced CP asymmetry measures the phase $\beta \equiv -\text{Arg}V_{td}$ controlling B^0 - \bar{B}^0 mixing to an accuracy of 1% [8].
- α : $B^0(t) \rightarrow \pi^+\pi^-$ involves direct CP violation from the interference between a dominant current-current amplitude carrying a weak phase γ and a smaller penguin contribution, which “pollutes” the measured $\sin \Delta mt$ term in the time-dependent asymmetry [8]. A ratio of penguin to tree amplitudes $|P/T| = 0.3 \pm 0.1$ in $B^0 \rightarrow \pi^+\pi^-$ is inferred [9] from the measured rates [10] of $B \rightarrow K\pi$ dominated by a penguin amplitude. Such a penguin contribution introduces a sizable uncertainty [11] in the determination of $\alpha = \pi - \beta - \gamma$ in $B^0 \rightarrow \pi^+\pi^-$. Isospin symmetry may be used [12] to remove this unknown correction to α by measuring also the time-integrated rates of $B^\pm \rightarrow \pi^\pm\pi^0$ and $B^0(\bar{B}^0) \rightarrow \pi^0\pi^0$. In the likely case that the decay rate into $\pi^0\pi^0$ cannot be measured with sufficient precision, one can at least use this measurement to set upper limits on the error in α [13]. Further out in the future, one may combine the time-dependence of $B^0(t) \rightarrow \pi^+\pi^-$ with the U-spin related $B_s(t) \rightarrow K^+K^-$ to determine separately β and γ [14]. This involves uncertainties due to SU(3) breaking.
- γ : The angle γ is apparently the most difficult to measure. It was suggested some time ago [15] to obtain information about this angle from charged B decays to $K\pi$ final states by measuring the relative phase between a dominant real penguin amplitude and a smaller current-current amplitude carrying the phase γ . This is achieved by relating the latter amplitude through flavor SU(3) [16] to the amplitude of $B^+ \rightarrow \pi^+\pi^0$, introducing SU(3) breaking in terms of f_K/f_π .

In the above two examples of determining α and γ , QCD penguin amplitudes were taken into account in terms of their very general properties, whereas electroweak penguin (EWP) contributions were first neglected and later on analyzed in a model-dependent manner [17]. Such an approach relies on factorization and on form factor

assumptions [18], and involves theoretical uncertainties in hadronic matrix elements similar to those plaguing ϵ'/ϵ [2].

In the present report we will focus on recent developments in the study of EWP contributions, which partially avoid these uncertainties, thereby improving the potential accuracy of measuring α and γ .

2 Model-independent treatment of electroweak penguins

The weak Hamiltonian governing B decays is given by [19]

$$\mathcal{H} = \frac{G_F}{\sqrt{2}} \sum_{q=d,s} \left(\sum_{q'=u,c} \lambda_{q'}^{(q)} [c_1 Q_1 + c_2 Q_2] - \lambda_t^{(q)} \sum_{i=3}^{10} c_i Q_i^{(q)} \right), \quad (1)$$

where $Q_1 = (\bar{b}q')_{V-A}(\bar{q}'q)_{V-A}$, $Q_2 = (\bar{b}q)_{V-A}(\bar{q}'q')_{V-A}$, $\lambda_{q'}^{(q)} = V_{q'b}^* V_{q'q}$, $q = d, s$, $q' = u, c, t$, $\lambda_u^{(q)} + \lambda_c^{(q)} + \lambda_t^{(q)} = 0$. The dominant EWP operators Q_9 , Q_{10} ($|c_{7,8}| \ll |c_{9,10}|$) have a (V-A)(V-A) chiral structure, similar to the current-current operators Q_1, Q_2 . Thus, isospin alone relates the matrix elements of these operators in $B^+ \rightarrow \pi^+ \pi^0$ [20]

$$\sqrt{2}P^{EW}(B^+ \rightarrow \pi^+ \pi^0) = \frac{3}{2}\kappa(T + C), \quad \kappa = \frac{c_9 + c_{10}}{c_1 + c_2} = -0.0088, \quad (2)$$

where $T + C$ represents graphically [16] the current-current amplitudes dominating $B^+ \rightarrow \pi^+ \pi^0$. Similarly, flavor SU(3) implies [20]

$$P^{EW}(B^+ \rightarrow K^0 \pi^+) + \sqrt{2}P^{EW}(B^+ \rightarrow K^+ \pi^0) = \frac{3}{2}\kappa(T + C), \quad (3)$$

$$P^{EW}(B^0 \rightarrow K^+ \pi^-) + P^{EW}(B^+ \rightarrow K^0 \pi^+) = \frac{3}{2}\kappa(C - E). \quad (4)$$

In the next three sections we describe briefly applications of these three relations to the determination of α and γ from $B \rightarrow \pi\pi$ and $B \rightarrow K\pi$, respectively.

3 Controlling EWP contributions in $B \rightarrow \pi\pi$

The time-dependent rate of $B^0 \rightarrow \pi^+ \pi^-$ includes a term $\sim \sin(2\alpha + \theta) \sin(\Delta mt)$, where the correction θ is due to penguin amplitudes [12]. Using isospin (2), the EWP contribution to θ , denoted by ξ , is found to be very small [20, 22]

$$\tan \xi = \frac{x \sin \alpha}{1 + x \cos \alpha}, \quad x \equiv \frac{3}{2}\kappa \left| \frac{\lambda_t^{(d)}}{\lambda_u^{(d)}} \right| = -0.013 \left| \frac{\lambda_t^{(d)}}{\lambda_u^{(d)}} \right|, \quad (5)$$

and is nicely incorporated into the analysis of Ref. 12 which determines α .

4 γ from $B^+ \rightarrow K\pi$

Using (3), EWP terms are included in the triangle construction of Ref. 15 [23]

$$\sqrt{2}A(B^+ \rightarrow K^+\pi^0) + A(B^+ \rightarrow K^0\pi^+) = \tilde{r}_u A(B^+ \rightarrow \pi^+\pi^0) (1 - \delta_{EW} e^{-i\gamma}) , \quad (6)$$

where $\tilde{r}_u = (f_K/f_\pi) \tan \theta_c \simeq 0.28$, $\delta_{EW} = -(3/2)|\lambda_t^{(s)}/\lambda_u^{(s)}|\kappa \simeq 0.66 \pm 0.15$. This relation and its charge-conjugate permit a determination of γ [15, 23] under the *assumption* that a rescattering amplitude with phase γ can be neglected in $B^+ \rightarrow K^0\pi^+$. This amplitude is bounded by the U-spin related rate of $B^\pm \rightarrow K^\pm \bar{K}^0$ [24, 25, 26]. Present limits are at the level of 20–30% of the dominant penguin amplitude [20, 27], and are expected to be improved to the level of 10%. In this case the rescattering effect, which depends strongly on the final state phase difference ϕ between $I = 3/2$ current-current and penguin amplitudes, introduces an uncertainty at a level of 15° in the determination of γ if ϕ is near 90° [28]. A considerably smaller theoretical error [27] would be implied if this measurable phase is found to be far from 90° .

Other sources of errors in γ , such as SU(3) breaking, are discussed elsewhere at this meeting [27, 29]. We note that in this determination of γ SU(3) breaking does not occur in the leading penguin amplitudes as it does in some other methods [14].

The phase γ can also be constrained by measuring only charge-averaged $B^\pm \rightarrow K\pi$ rates. Defining

$$R_*^{-1} = \frac{2[B(B^+ \rightarrow K^+\pi^0) + B(B^- \rightarrow K^-\pi^0)]}{B(B^+ \rightarrow K^0\pi^+) + B(B^- \rightarrow \bar{K}^0\pi^-)} , \quad (7)$$

one finds using (3) [20, 21]

$$R_*^{-1} = 1 - 2\epsilon \cos \phi (\cos \gamma - \delta_{EW}) + \mathcal{O}(\epsilon^2, \epsilon_A^2, \epsilon\epsilon_A) , \quad (8)$$

where [15, 21] $\epsilon = \tilde{r}_u \sqrt{2}|A(B^\pm \rightarrow \pi^\pm\pi^0)/A(B^\pm \rightarrow K^0\pi^\pm)| \sim 0.24$, while ϵ_A is the suitably normalized rescattering amplitude. The resulting bound

$$|\cos \gamma - \delta_{EW}| \geq \frac{|1 - R_*^{-1}|}{2\epsilon} , \quad (9)$$

which neglects *second order* corrections, can be used to exclude an interesting region around $\cos \gamma = \delta_{EW}$ if $R_*^{-1} \neq 1$ is measured. Again, this would be very difficult if $\phi \simeq 90^\circ$. The present value of the ratio of rates is [10] $R_*^{-1} = 2.1 \pm 1.1$.

5 γ from the ratio of $B^0 \rightarrow K^\pm\pi^\mp$ to $B^\pm \rightarrow K^0\pi^\pm$ rates

Denoting this ratio of charged-averaged rates by R [30], one finds using (4) a constraint very similar to (9) [20, 22, 26]

$$|\cos \gamma - \delta'_{EW}| \geq \frac{|1 - R|}{2\epsilon'} \quad (10)$$

where $\delta'_{EW} \sim 0.2\delta_{EW} \sim 0.13$ represents color-suppressed EWP contributions, and [25] $\epsilon' \sim 0.2$ is the ratio of tree to penguin amplitudes in $B^0 \rightarrow K^+\pi^-$. In contrast to (9), this bound neglects *first order* rescattering effects, and the values of δ'_{EW} and ϵ' are less solid than those of δ_{EW} and ϵ in (9). Eq. (10) can exclude a region around $\gamma = 90^\circ$ if $R \neq 1$ is found. Presently [10] $R = 1.07 \pm 0.45$.

6 Conclusion

- In $B \rightarrow \pi\pi$ strong and electroweak penguins are controlled by isospin.
- In $B \rightarrow K\pi$ strong penguins dominate and EWP are controlled by SU(3).
- Interesting bounds on γ , in one case susceptible to rescattering effects, are implied if the $B \rightarrow K\pi$ charge-averaged ratios of rates differ from 1.
- A precise determination of γ from $B \rightarrow K\pi$ is challenging and requires a combined effort involving further theoretical and experimental studies.

Acknowledgment: This work is supported by the United States – Israel Binational Science Foundation under Research Grant Agreement 94-00253/3.

References

- [1] P. Shawhan, University of Chicago, Fermilab seminar, Feb. 24 1999.
- [2] E.A. Paschos, these proceedings.
- [3] For two recent reviews, see R. Fleischer, *Int. J. Mod. Phys. A***12**, 2459 (1997); M. Gronau, *Nucl. Phys. Proc. Suppl.* **65**, 245 (1998).
- [4] M. Kobayashi and T. Maskawa, *Prog. Theor. Phys.* **49**, 652 (1973).
- [5] This is a very short summary of a 45 minute review talk presented at this conference. Relevant references are included for further details.
- [6] CDF Collaboration, report CDF/PUB/BOTTOM/CDF/4855, Feb. 5 1999.
- [7] A.B. Carter and A.I. Sanda, *Phys. Rev. Lett.* **45**, 952 (1980); *Phys. Rev. D* **23**, 1567 (1980); I.I. Bigi and A.I. Sanda, *Nucl. Phys. B* **193**, 85 (1981).
- [8] M. Gronau, *Phys. Rev. Lett.* **63**, 1451 (1989); D. London and R.D. Peccei, *Phys. Lett. B* **223**, 257 (1989); B. Grinstein, *ibid* **229**, 280 (1989).
- [9] A. Dighe, M. Gronau and J.L. Rosner, *Phys. Rev. Lett.* **79**, 4333 (1997).

- [10] CLEO Collaboration, R. Godang *et al.*, *Phys. Rev. Lett.* **80**, 3456 (1998); J. Alexander, Rapporteur's talk at the 29th International Conference on High Energy Physics, Vancouver, B.C., Canada, July 1998.
- [11] M. Gronau, *Phys. Lett. B* **300**, 163 (1993).
- [12] M. Gronau and D. London, *Phys. Rev. Lett.* **65**, 3381 (1990).
- [13] Y. Grossman and H.R. Quinn, *Phys. Rev. D* **58**, 017504 (1998); J. Charles, *ibid* **59**, 054007 (1999); L. Oliver, these proceedings; D. Pirjol, hep-ph/9903447.
- [14] I. Dunietz, Proceedings of the Workshop on *B* Physics at Hadron Accelerators, Snowmass, CO, 1993, p. 83; R. Fleischer, CERN-TH/99-79, hep-ph/9903456.
- [15] M. Gronau, J.L. Rosner and D. London, *Phys. Rev. Lett.* **73**, 21 (1994).
- [16] M. Gronau, O. Hernández, D. London and J.L. Rosner, *Phys. Rev. D* **50**, 4529 (1994).
- [17] N.G. Deshpande and X.G. He, *Phys. Rev. Lett.* **74**, 26 (1995); O.F. Hernández *et al.*, *Phys. Rev. D* **52**, 6374 (1995); R. Fleischer, *Phys. Lett. B* **365**, 399 (1996).
- [18] A. Ali, G. Kramer and C.D. Lu, *Phys. Rev. D* **59**, 014005 (1999); X.G. He, W.S. Hou and K.C. Yang, *Phys. Rev. Lett.* **81**, 5738 (1998); N.G. Deshpande X.G. He, W.S. Hou and S. Pakvasa, *ibid* **82**, 2240 (1999).
- [19] G. Buchalla, A.J. Buras and M.E. Lautenbacher, *Rev. Mod. Phys.* **68**, 1125 (1996).
- [20] M. Gronau, D. Pirjol and T.M. Yan, hep-ph/9810482, *Phys. Rev. D* (in press).
- [21] M. Neubert and J.L. Rosner, *Phys. Lett. B* **441**, 403 (1998).
- [22] A.J. Buras and R. Fleischer, CERN-TH/98-319, hep-ph/9810260.
- [23] M. Neubert and J.L. Rosner, *Phys. Rev. Lett.* **81**, 5076 (1998).
- [24] A. Falk, A.L. Kagan, Y. Nir and A. A. Petrov, *Phys. Rev. D* **57**, 4290 (1998).
- [25] M. Gronau and J.L. Rosner, *Phys. Rev. D* **57**, 6843 (1998); **58**, 113005 (1998).
- [26] R. Fleischer, *Phys. Lett. B* **435**, 221 (1998); *Eur. Phys. J. C* **6**, 451 (1999).
- [27] M. Neubert, these proceedings; CERN-TH/98-384, hep-ph/9812396.
- [28] M. Gronau and D. Pirjol, CLNS 99/1604, hep-ph/9902482.
- [29] R. Fleischer, these proceedings; Ref. 22, 26.
- [30] R. Fleischer and T. Mannel, *Phys. Rev. D* **57**, 2752 (1998).